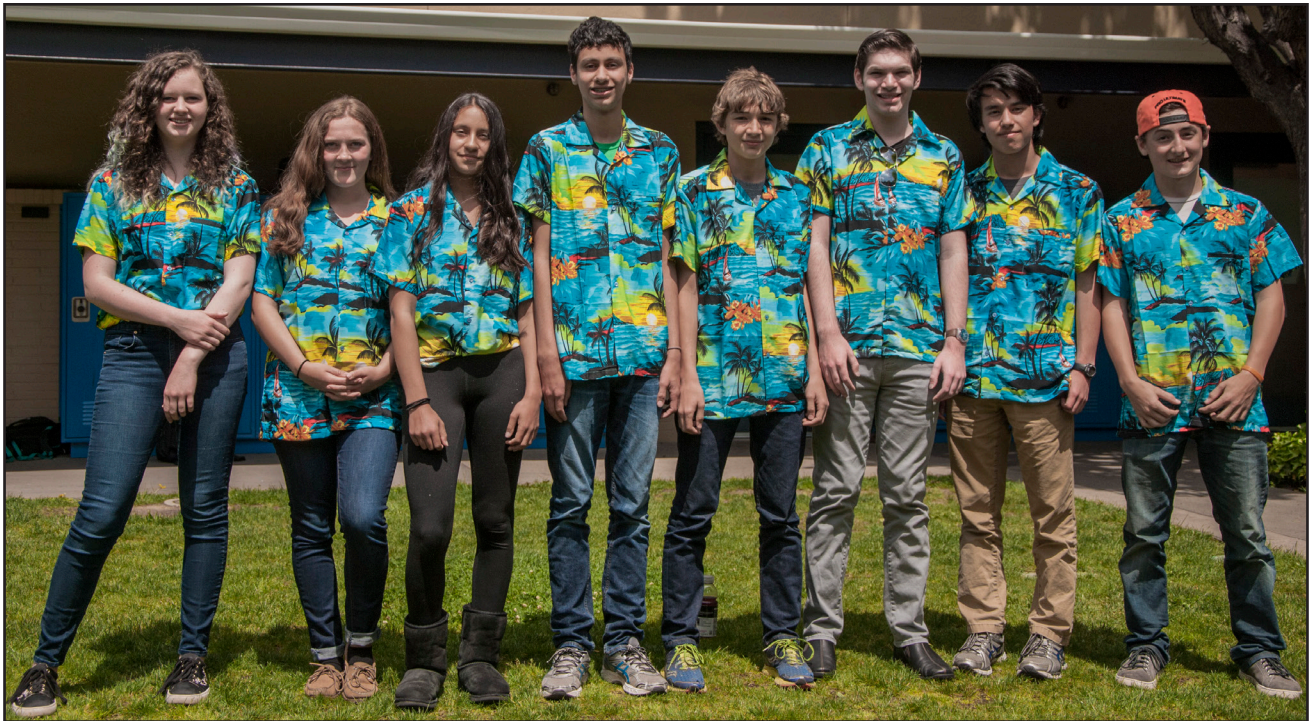




PHOENIX ELECTRONICS

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Celvi Lisy, 2019: Electrical Engineer

Rohan Tuli, 2017: Director of Communications / Head Electrical Engineer

Connor Tingley, 2018: CEO / Head Software Engineer

George Serwin, 2017: CFO / Head of Safety

Chip Morimoto, 2019: Pilot / Mechanical Engineer

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Abstract

The Artaboki (Fig. 1) is the latest Remotely-Operated Vehicle from the Phoenix Electronics team, and it is specialized to do several tasks similar to those in the Port of Long Beach. The Artaboki is designed to be able to aid in the construction of the hyperloop, work maintenance on a light and water show, perform an environmental cleanup, and provide risk mitigation by surveying an area and determining what could prove hazardous and where the hazardous materials are located. In order to accomplish these tasks, our ROV comes equipped with a claw to complete the general tasks and specialized tools such as a sediment collector to be able to retrieve the simulated sediment of agar on the pool floor. The Artaboki is optimized in size and weight to ensure that our ROV has the agility and compactability to move smoothly and efficiently through the water. Our team, Phoenix Electronics, is from Bentley Upper School in Lafayette, California. 2017 marks Bentley's seventh year in the MATE ROV competition. Phoenix Electronics has eight members that are very well-rounded in order to make an ROV that is able to complete the given tasks. Our team worked very hard over the period of nine months in order to be able to create an ROV with the ability to operate and repair in the Port of Long Beach.

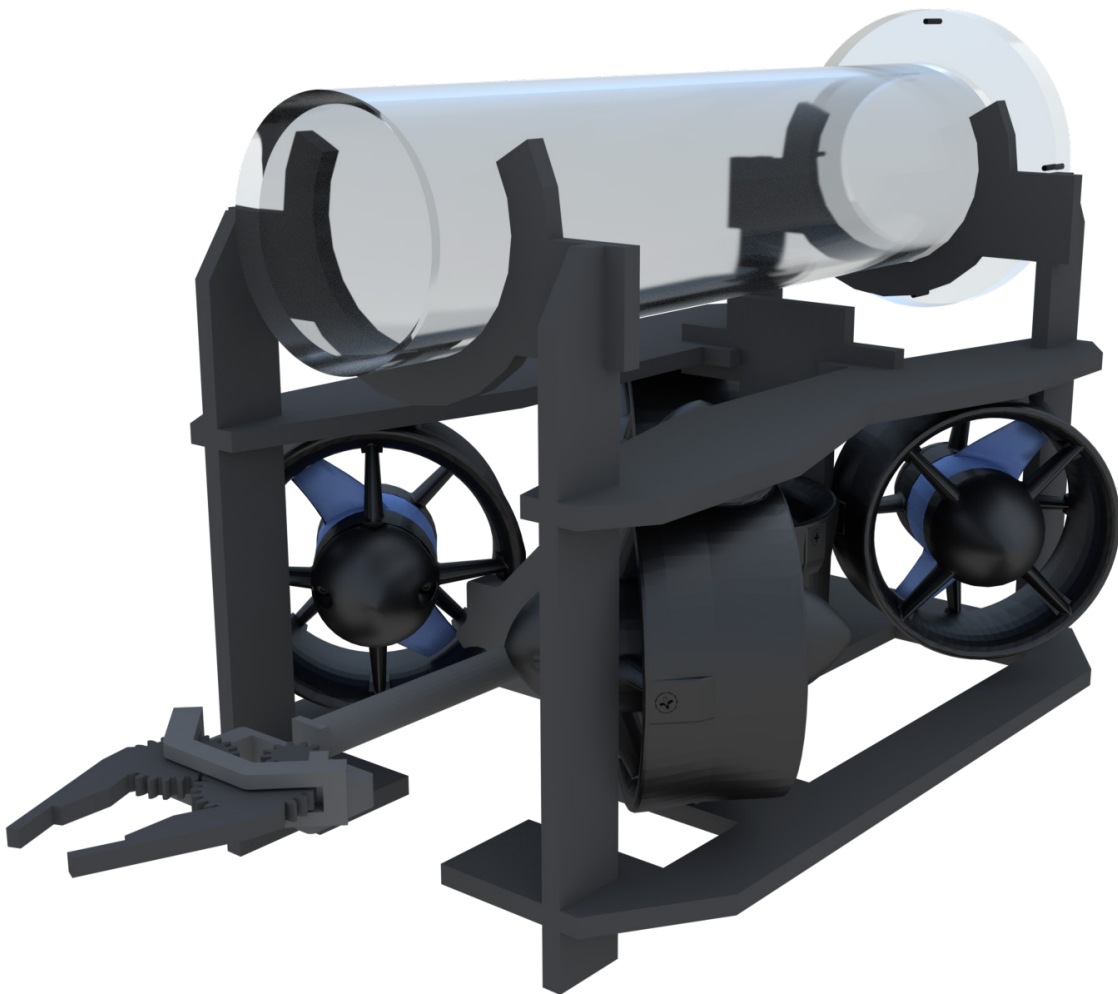


Fig. 1: A computer rendered 3D model of The Artaboki.

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Theme Significance

Ports are some of the busiest and most crowded areas of the oceans, for example in the Port of Long Beach (Fig. 2), there is hyperloop construction and light and water shows. As of 2013, nearly half of the carbon monoxide and nitrogen oxides were caused by air pollution from cars and other methods of transportation. In our current state, there is a great need for better public transportation, which is why the construction of the hyperloop is vital to our environment. Because of this, there is a need for a compact and agile machine to be able to not only aid in the construction of the hyperloop and maintenance of the light and water shows, but also ensure that there are no hazards in the water and that the ocean remains an environment sea life is not only able to live but prosper. Ocean and coastline pollution can lead to large blooms of algae that can consume the majority of the oxygen in the ocean so that sea life cannot survive in that region. These regions are called dead zones in the ocean and as of now there are more than four hundred dead zones in the ocean. That is why we constructed an ROV to be able to examine sealife polluted by boat traffic, construct new features for cleaner transportation, and maintain customer entertainment without interrupting operations. ROVs that are able to assist hyperloop construction are advancing the shipping and transportation industry by creating offshore docking areas that will help free more beach space for the population's use. This will also drastically improve shipping efficiency of the port by creating as many necessary. Ships often have to wait days to dock at the port, costing shipping companies money and causing ships to spend days releasing smog into the air, harming the surrounding communities. With pollution in Long Beach largely contributed to by commercial shipping traffic, ROVs building this hyperloop would directly can aid the health of the population of Long Beach, while also making it easier to assess and treat pollution. ROVs can be essential to testing levels of pollution in sea life. ROVs can use techniques such as Raman spectroscopy to determine contaminates on the ocean floor, and remove contaminated sediment to aid in the environmental remediation of the area. With robots tending to the ocean floor, there would be no need to stop commerce to and from the ports. ROVs can also oversee underwater repairs and adjustments to the port's new water and light show, without the need for humans to go below the surface. This light show serves as one of the many tourist attractions in the port, bringing in tourists to help the tourism industry, which makes up a large part of the local economy. The ROVs can also play a role in preserving the security and safety of the port. With over 80 million shipping containers, it is not uncommon for such containers to fall off of cargo ships into the ocean surrounding the port. These containers can contain hazardous cargo, such as explosives, radioactive material, and corrosive and toxic substances. ROVs can help the port mitigate the risks associated with these sunken containers, such as helping locate the shipping containers, using radio frequency identification tags to determine the container's contents and determine whether they contain any hazardous cargo, and finally mapping the area of risk around the containers.



Fig. 2: A photo of the Port of Long Beach showing the intermodal shipping facility and the queue of ships.

Company Profile

Phoenix Electronics is a returning competitor in the MATE competition. While Phoenix Electronics has operated for 7 years, current members have up to 6 years of experience in ROV, both with Phoenix Electronics and with other teams. Three of our current members were part of the Phoenix Electronics team that won first place in the 2015 Navigator division and third place in the 2016 Ranger division. After its inception in 2011, Phoenix Electronics experimented with many different leadership and management structures. This year, we have implemented our most effective system yet. Our company has a flat management structure, to balance independence and cooperation to minimize bureaucracy and maximize efficiency. We have a Chief Executive Officer (CEO), Chief Financial Officer (CFO), and Director of Communications; these individuals lead the team and keep us focused and informed. However, instead of designating specific tasks for each team member, members decide their own projects and what to work on, both solo or in small groups. Each solo member or group works independently, but in close communication with the team leadership as well as the rest of the team, receiving feedback without leadership micromanaging individuals. Certain individuals take charge of specific areas of product development and communications (e.g. technical writing, financial management, collecting references and MATE documents, etc), and help guide those sub-teams in order to complete major tasks (e.g. designing and assembling the control box) in a timely and organized manner. This organizational structure promoted productivity by creating a space for the free flow of ideas and constructive criticism, which ultimately lead to our team creating a fluid and fully functional robot.

Project Management and Scheduling

Phoenix Electronics began meeting on September 24th, 2016 and met every Saturday for 3-4 hours. As we approached the competition, we began also meeting after school twice a week for 2 hours. In order to make sure that our Makerspace is as clean and organized as possible, we also had “Improvement” days where we would spend two hours putting forgotten tools back in their places, reorganizing and cleaning our team boxes, etc. In order to make sure our team had plenty of time to complete and practice with our bot we implemented a strict attendance policy, asking that people only miss a maximum number of six practices (not including absences due to illness). Our CEO and CFO, meet a half hour before the meetings in

order to prepare the makerspace and brainstorm improvements to the ROV. When we began meeting we composed a baseline list of what things needed to be made/designed (e.g. control box, frame, hydrotube, cameras, tools) and split into small groups (2-3 people) based on interest. While these groups mingled throughout the year and everyone became involved in multiple aspects of

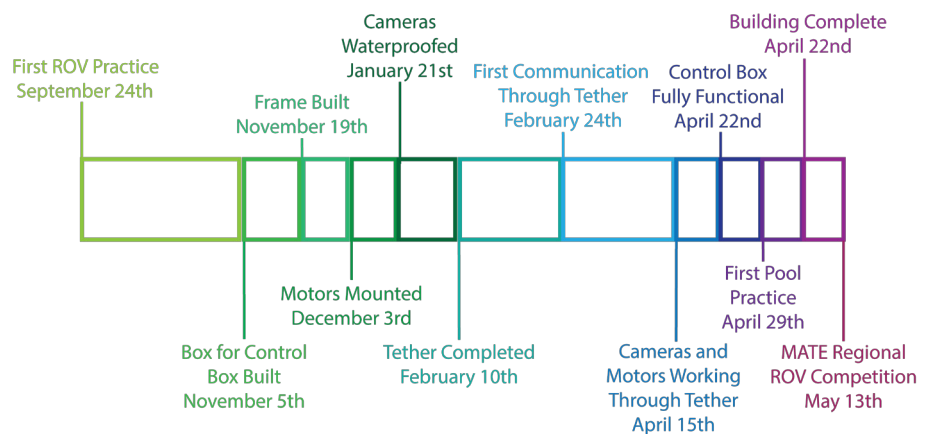


Fig. 3: A timeline of the significant milestones in the process of building “The Artaboki”.

the bot, they helped us to stay organized and to have clear leader(s) for each section of the ROV. At the end of each meeting all team members met together to share out what they accomplished during the meeting and what they wish to accomplish next week. We also used a to-do list (Appendix B) to stay on task and complete projects in a timely and efficient manner. This to-do list was shared with everyone to ensure that everyone would be productive and no tasks would be repeated. As a team our goal was to have the bot ready for the pool by mid April, so that we would have an ample amount of pool practice (Fig. 3). Our bot was fully constructed by this time but we ran into technical problems that delayed when we could realistically get in the pool by a few weeks. As we approached the competition, our practice times began to both increase in length and frequency for troubleshooting and pool practice, as well as presentation practice and technical writing. Currently we are meeting 4 times a week for 2-3 hours at a time.

Safety

— Philosophy

Safety is our first priority at Phoenix Electronics, as we identify possible risks in all tasks and take the necessary precautions to insure our 100% safety guarantee. In order to remain safe at all times, we have a strict set of rules for both our Makerspace and poolside. First and foremost, members are required to wear closed toed shoes, long pants, and pulled up hair at all times when in the Makerspace and when working on the ROV. Safety masks are also used when cutting dust-releasing materials as well as when epoxying. Everyone is required to use safety goggles at all times (Fig. 4) when cutting and soldering, and ear protection, as well as an adult supervisor being necessary to the operation of power tools. All new recruits are trained on how to safely use all tools and substances in the Makerspace by the faculty mentors and the Director of Training, before they are allowed to operate said tools on their own. Our Makerspace is also stocked with nitrile gloves



Fig. 4: Keaton ('19) using protection.

for the use of epoxy or other potentially hazardous materials. Our team is very focused on improving the safety environment of our Makerspace, even having weekly Thursday meetings dubbed as makerspace improvement days. During this time, we build tables and shelves as well as organize and label everything. With more work space and storage, the safety of our makerspace is greatly improved as there is no clutter and everyone has a safe surface to work on. Clutter in the makerspace can cause people to trip, which leads to injuries. A clean working space also helps everyone to easily find the correct tools for the tasks at hand rather than spending precious time searching.

— Features

One of our first concerns for ROV safety was ensuring that our ROV and control box is “baby-proof,” including safety features such as shrouded motors, rounded edges, non swallowable pieces, as well as waterproofing electronics and electrical connections to prevent shocking. In terms of waterproofing, our main concern was the hydrotube; in past years, water has leaked in which both destroys the electronics and creates a dangerous situation. We vacuum-tested the hydrotube, meaning that we pulled a vacuum and tested to see if air leaked in. If atmospheric pressure cannot

penetrate the hydrotube, water pressure at 12 Meters cannot either. In this way, we could ensure that the hydrotube was sealed without risking water damage. Along with the hydrotube, all underwater soldering connections were triple waterproofed with heat shrink, hot glue, and a layer of five-minute epoxy. The plugs used for the motors and cameras were water proofed by the manufacturer and we added epoxy on either end where the wires exit. For the claw, we bought Hitec Servos and waterproofed them by deconstructing each servo and coating all electronics, gears, and inside surfaces with marine grease, a hydrophobic lubricant made specifically for waterproofing. Our motors are provided by Blue Robotics, which fabricates strong, pre-waterproofed motors, which make them particularly beneficial. We added additional waterproofed the motors by precisely applying epoxy to the seams to prevent water leaking into the motor housing. We bolted down our motors to insure that the motors will be stable and not disconnect from the ROV.

— Safety Checklist —

— During Construction Checklist —

- ✓ Close-toed shoes
- ✓ Long pants
- ✓ Tied back hair
- ✓ No loose clothing
- ✓ Safety glasses worn while using tools or soldering
- ✓ Rubber gloves and dust masks / respirators when handling epoxy
- ✓ Proper air ventilation at all times
- ✓ Dust masks/respirators when working with anything with fumes
- ✓ Proper workshop behavior (no running / horseplay)
- ✓ Proper training on all power tools
- ✓ All flammables stored in flammables cabinet

— Pre-Mission Checklist —

- ✓ All items on ROV are properly secured
- ✓ No exposed wiring or propellers
- ✓ All wiring is secured
- ✓ Tether is secured to both ROV and control box with proper strain relief
- ✓ Tether is uncoiled and untangled
- ✓ Deck crew has hair tied back and is wearing close-toed shoes and long pants
- ✓ Main power switch is off until all electrical connections have been connected, checked, and double checked
- ✓ Main power switch is powered on once all deck crew members say “ready”

Design Rationale and Composition —

— Underwater —

— Motors —

After much contemplation, we chose to use T100 motors from Blue Robotics (Fig. 6) because they produce maximum thrust with minimal current draw. These brushless motors produce more thrust than the 1250 gph bilge pump motors that we previously used, letting us have better control and speed of movement in the water. Given that we have 15 minutes to complete our task we found that the speed of the T100 motors was a big benefit. The motors were expensive but we decided the quality, ease, and safety they provided us was well worth the money. Each motor individually produces 23.13 Newtons of thrust in the forward direction and 18.13 Newtons of thrust in the reverse direction. The maximum current draw for all motors is 9.6 Amps which was tested on our motor testing rig. All motor leads were cut

to a 15 centimeter length, and then soldered onto one side of a waterproof plug with the other side attached to the hydrotube which then connects to the electronic speed controllers (ESCs). By unplugging the waterproof connector and then removing the motors from the frame, the motor can be switched out for a replacement. This year we also bought a spare motor, as last year one of our motors broke on competition day and we were unable to replace it.

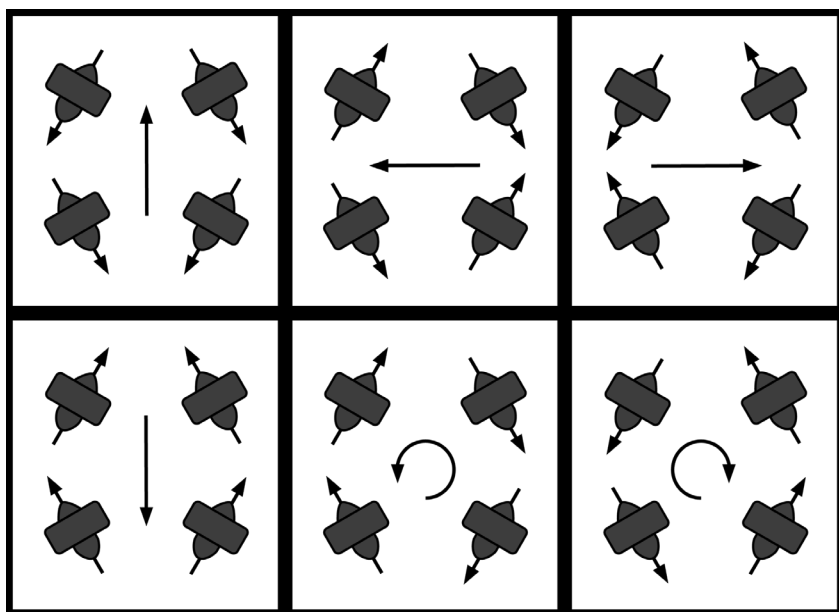


Fig. 5: Motor vectoring diagram.

There are five motors mounted to our ROV, four of which move the ROV horizontally and the last of which is used to move the ROV vertically. Five motors both allows us to be compact and light, while also having ample maneuverability both vertically and horizontally. Our horizontal motor vectoring orientation (Fig. 5, 7) maximizes the ratio of forward, strafing, and rotational thrusts, providing superior maneuverability and allowing us to move through tasks with increased speed, efficiency, and control. Last year we used a similar motor vectoring system, but this year we increased the motor angle to 30° for improved strafing ability. Given the power of our motors, we only require one vertical motor letting us house all of our motors inside the frame of the ROV in order to stay compact for maneuverability and size restrictions. A problem we ran into was our motors having too much power, which held us back from fine movements. In order to rectify this we made the potentiometer on the joystick control the throttle for the robot, letting us turn down the throttle to make slower and more deliberate movements in the water while still being able to use full throttle when moving between tasks.

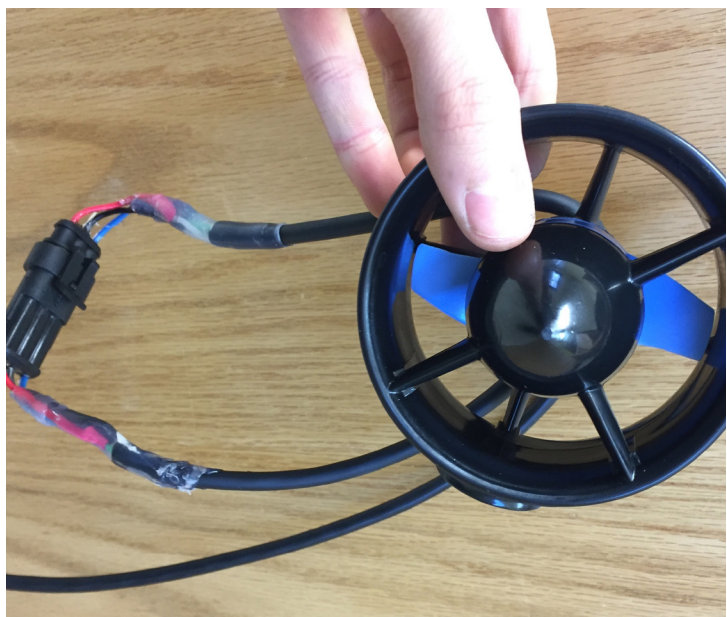


Fig. 6: A Blue Robotics T100 thruster with a waterproof plug.

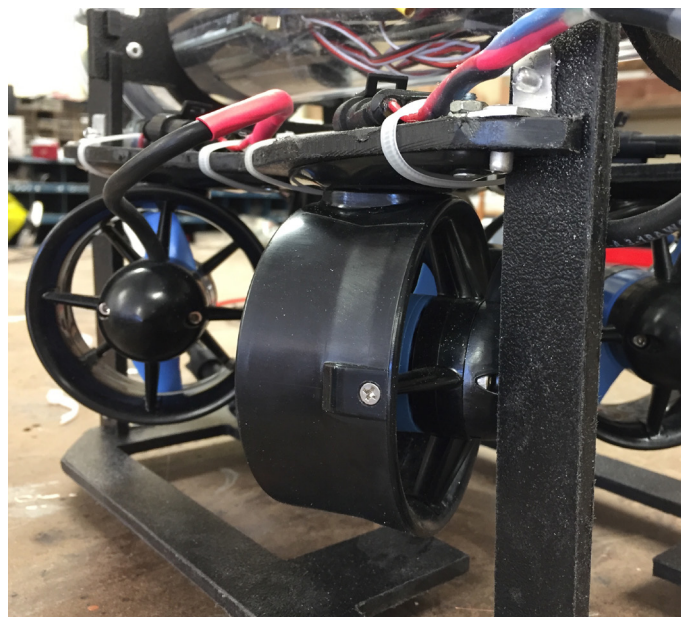


Fig. 7: Hexagonal motor configuration mounted onto "The Artaboki".

Frame

The frame (Fig. 8) was designed around our motor vectoring system, in order to accommodate four horizontal motors as well as provide ample mounting along the bottom for tools. The frame was designed to have 3 levels, each for a different purpose, supported by 4 vertical struts. The highest level holds the hydrotube in place and consists of two crescent brackets mounted between the vertical struts. The hydrotube is mounted on the top of the ROV, as it is our main source of flotation and its position provides rotational stability. The middle level holds the 4 horizontal motors as well as the vertical motor bracket, and consists of 2 wings that each hold 2 motors. These wings are angled to hold the motors at 60° increments for easier mounting. The bottom level holds our tools and ballast, including mounting spots for the claw, agar collector, and LED. This is very helpful for completing tasks

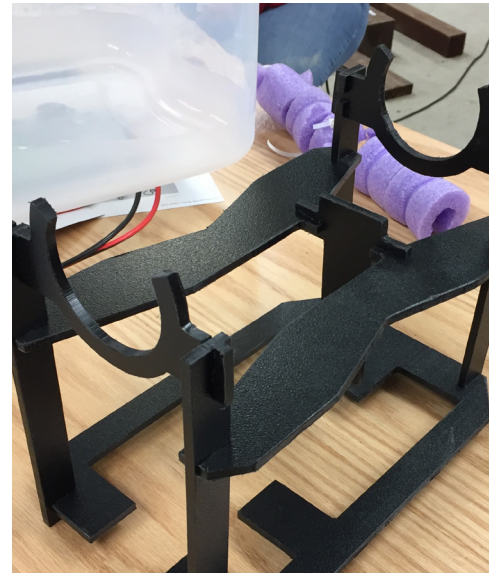


Fig. 8: A baby photo of our newly born frame.

because it allows the ROV to move down less and to pick things up from the bottom of the floor with our claw. We modeled the frame in Google Sketchup, and CNC routed it out of high density plastic for robotic precision.

Cameras

Our ROV uses 4 analog car backup cameras. The cameras (Fig. 9) are small which is beneficial given that they will not take up too much space on the bot and can fit anywhere. They are also reasonably priced (around \$30 a camera). These cameras were pre-waterproofed, but we additionally waterproofed them using a thin coating of epoxy at all potential points of failure. Each of the cameras was attached to the rest of the tether with a disconnectable waterproof plug. This meant that if a camera was to fail, it would be easily replaceable without any new soldering. The backs of the waterproofed plugs were also epoxied as an extra precaution. Similar to the motors, we have one extra camera that can easily replace any of the others in case we encountered problems. The cameras are held in place by custom aluminum brackets and secured using bolts. We encountered problems once we began mounting them, realizing that two of the cameras were epoxied in incorrect orientations. Another complication we encountered was that, roughly a week before the competition, water leaked into the plugs and short circuited our cameras, making it impossible to see the ROV's location in the pool. We quickly replaced all four cameras, using our extra one, re-epoxying and mounting them onto the bot. More complications arose when condensation began to form on the lenses of these new cameras, resulting in increased difficulty for the driver. In order to not replace these new cameras again, we used a hair dryer to remove water from the lenses and then re-epoxied the seam around the lenses of the cameras.



Fig. 9: One of our cameras.

Hydrotube

The hydrotube (Fig. 10, 11) is composed of an acrylic tube with a diameter of 7.62 centimeters by 38.5 centimeters long. We chose this size tube as it is the optimal size to hold our onboard electronics and has enough volume to make the ROV slightly positively buoyant. The tube is sealed on one end

with a CNC cut cap, secured with E-6000 acrylic glue, which sits flush on the top of the tube. On the other end there is a flange that we CNC-routed out of a 0.635 centimeter thick by 14 centimeter diameter piece of acrylic glass. In the acrylic, there is a groove that is cut around the tube in which there is a custom fit rubber gasket sealing the tube. Then there is a CNC-routed cap of acrylic glass that bolts tight onto the flange, squeezing the rubber gasket between matching grooves. The gasket is also coated in a silicon-based lubricant to further prevent water from entering. The cap has holes to allow wires to exit the hydrotube and enter into the tether. The wires are fed through the holes and then the holes are sealed with epoxy. We took these precautions in order to have a perfectly sealed tube because it is dangerous to let water come into contact with the exposed electronics inside. We also included a system that would allow us to pull a vacuum in the tube, letting us identify any leaks that appeared before submerging the robot in water as we would lose pressure. To find leaks we also submerged the hydrotube and slightly pressurized it looking for bubbles where leaks were present.



Fig. 10: Keaton ('19) with the hydrotube.

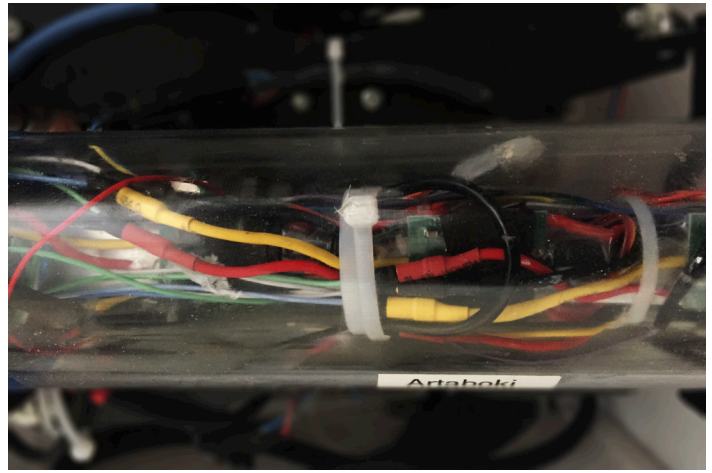


Fig. 11: The interior of the hydrotube.

Bouyancy and Ballast

We designed the hydrotube to give the robot all of its flotation. Adding weight to the bot to make it neutrally buoyant that we have more control over how the bot sits in the water.

$$r = \text{Hydrotube radius (cm)} \quad h = \text{Hydrotube length (cm)} \quad m = \text{ROV mass (kg)} \quad b = \text{Added ballast (kg)}$$

$$(r^2h)(1 \text{ gcm}^3) \cdot (1 \text{ kg}/1000 \text{ g}) - m = b \quad \rightarrow \quad ((7.5 \text{ cm})^2 \cdot 37.5 \text{ cm}) \cdot (1 \text{ gcm}^3) \cdot (1 \text{ kg}/1000 \text{ g}) - 6.61 \text{ kg} = b \quad \rightarrow \quad b = 0.017 \text{ kg}$$

Tether

The tether (Fig. 12) consists of three different main sections: the RCA camera cables, the shielded twisted pair cable, and the main power wires. We initially planned on using a VGA cable to carry the camera signals and a Cat 5 cable to carry the signals between the two arduinos, however this setup was very unreliable (further briefed on page 19). We are using RCA cables to carry camera signals for two reasons; they are designed for carrying camera signals and so the wires are the correct gauge and the connectors are standardized and so we can connect the cables directly to other components without having to solder on new connectors. We are using a shielded twisted pair cable to carry arduino signals because there is very little signal drop across the distance. We are using four 10



Fig. 12: The attachment point of the tether to the control box, showing strain relief.

AWG power cables that deliver electricity to the robot. We chose to use much thicker cables than last year to carry the power in order to reduce the amount of voltage drop from 25.1% to 8.33% (Fig. 13). We also enclosed all of the wires in a flexible nylon sheath, which keeps the tether contained while at the same time remaining lightweight and hydrodynamic.

Onboard Electronics

Located onboard the ROV, we have an Arduino MEGA and 6 electronic speed controllers (ESCs). These components are housed within the hydrotube which not only permits a thinner tether, but also creates a smaller voltage drop to our high current components. This means that our motors get a larger voltage, increasing their speed, and helping us accomplish the tasks more efficiently. In last year's design, the ESCs were topside, requiring that each of the five motors have three wires carrying 5 Amps separately. Since we needed 15 wires in the tether, each had to be thin (18 AWG), which meant that we were losing about 25% of our voltage to heat due to resistance. With onboard electronics, however, each ESC needs a +12 Volt power, a ground, and a signal, of which two (the power and ground) are universal between motors. This means that all of our motor wires only require 2 voltage bearing wires, and 5 micro signal wires total. However, we decided to further simplify it by adding the onboard Arduino. Instead of each variable requiring a wire to communicate, the Arduino processes the variables into a bit array and can send all of the variables along 2 wires. To do this, we originally paired the onboard Arduino with the Arduino Wire Library which allows variable communication through the tether with only 2 wires. We encountered issues however, as the Wire Library uses the I2C Protocol, which is not meant to travel over long distances, and is very vulnerable to interference. With the camera signals and 12V power cables running directly beside the I2C connection in the tether, the arduino connection became corrupted and was unable to pass signals through the tether. This meant that our bot became unable to connect to the control box, and we lost control of the motors. After finding this out a week before the regional competition, we had to quickly replace the system with an active USB cable, running along the tether. Once again, we ran into the problem of signal length, when on the day of the regional competition, the USB signal cut out. After forfeiting our first product demonstration, we finally got the motors running. However, in our second and only remaining product demonstration, the USB system failed again. From this we learned the necessity for signal formats that are designed for long, noisy distances, and are now implementing two RS-485 arduino shields for data communication.

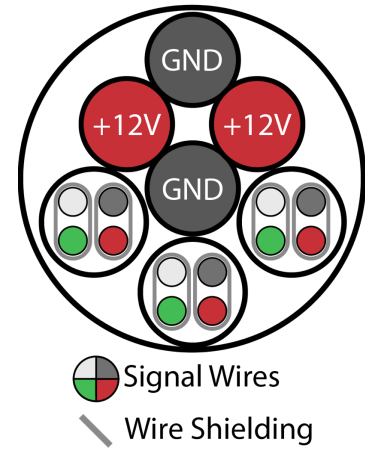


Fig. 13: Tether cross section. Power (+12V and GND) wires are 10 AWG and signal wires are shielded and 18 AWG.

Tools

Simulated Ramen Spectrometer

Our simulated Raman Spectrometer was built focusing on simplicity, practicality, and effective range. It is essentially a red LED flashlight, made from four red LEDs and a scrapped LED flashlight casing. We cut off the end of the casing, allowing access to the reflective cone in the head of the flashlight. The LEDs were installed into a gap in the base of the reflective cone, increasing the effective range of the LEDs. The reflective cone directs the light from the LEDs forwards, taking advantage of light that would have otherwise not illuminated the sediment sample. The end of the flashlight casing is slid back into the head of the flashlight, creating a casing to be filled with epoxy to waterproof the LEDs. We used LEDs instead of a laser because we could easily and

affordably build our own simulated Raman spectrometer. Additionally, we could increase the amount of light emitted by the spectrometer, as well as increase the area that the spectrometer illuminates, increasing visibility.

Claw

The claw (Fig. 14) was designed to be a multi-purpose tool, able to complete the majority of the physical manipulation tasks underwater. For this reason, the claw has 2 axes of control, both of which are powered by servos. Both of these servos were waterproofed by our company and tested extensively underwater to ensure quality control. The first axis is the grabbing mechanism, used for grasping and releasing props with a strength of 90.2 Newtons. The strength is derived from the torque beneficial gear system where the claw arms rotate half the distance of the servo, but in turn, exert double the force on the prop. This claw strength is a necessary improvement to our design. On a few occasions last year props slipped out of our claw, not only failing to complete the task but also littering the seafloor. The claw arm also comes fitted with a multi-use gripper system, custom built to hold many separately sized objects of different diameters from PVC, to rope, to U-bolts, and even velcro. The whole system is mounted onto a rotating extension, permitting the claw's rotation from the front of the ROV to the bottom. This means that our claw can interact with both props on the seafloor and vertical faces. The superior movement is not only useful for adjusting grip position to grab differently oriented props, but also allow the ROV to complete additional tasks that may not be planned for. The claw was designed completely by our team in Sketchup and 3D-printed on site, with a total of 5 iterations of testing and improvement.



Fig. 14: The claw and its plugs.

Sediment Collector

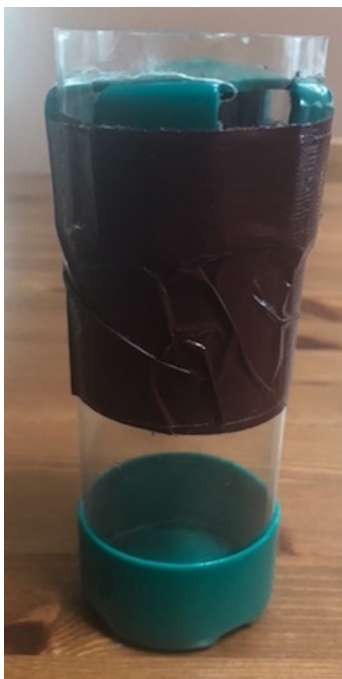


Fig. 15: The sediment collector.

We have designed a sediment collector (Fig. 15) to pick up sediment off the seafloor that is contaminated for further examination. Our initial plan for the sediment collector was to use an Archimedes screw. After several tests, we realized that it was too difficult for the screw to collect the sample because the screw could not reliably hold the sediment, as well as not being able to puncture the surface of the sediment. We then decided to try using a simple tube to pick up the sediment. The simulated sediment was too slippery to stay inside of the smooth interior of the container, and the sample we attempted to collect did not break away from the rest of the sediment. Next we designed a scoop-like tool to obtain the agar, but abandoned the idea because it would be hard to keep the sediment in the scoop. We then designed a super-sized syringe system to suck up the sediment. After realizing that the syringe system would not be able to hold enough hard sediment after testing a prototype, we changed the design to a plastic cylinder with a slit in one end of the tube. The plastic cylinder has a rubber cover over the end of the cylinder that has a slit in the middle. It will open when the cylinder is placed onto the sediment sample. When the cylinder is pulled out of the sediment, the

the slit closes, preventing the sediment from exiting the cylinder. A few holes were drilled on the upper edge of the tube to allow the water to leave the cylinder as sediment fills the space. We made a mount that would attach the collector to the rear of the robot so that was easy to slide on and off while also being easy to correct the mount.

Bouy

In order to mark the hazardous cargo container, we developed a buoy deployment system (Fig. 16) designed to be easily and reliably secured to a U-bolt on the cargo container. We drew from previous experience and successes, redesigning and repurposing a tool our previous Phoenix Electronics team had developed for the MATE competition two years prior. The deployment system utilizes a butterfly drywall anchor attached to a long bolt, which functions as a grappling hook when pushed through a U-bolt. The grappling hook is carried by a pen casing attached to the bottom of the ROV, so that once the grappling hook is connected to the hazardous cargo container, it would slide out of the pen casing when the ROV reversed away. This year, we slightly modified the design, adding a metal fitting that extended vertically off of the grappling hook. The line to which the buoy was attached was then secured to the grappling hook via this new fitting. The buoy line was made from neon green paracord, which is both thick enough to not get sucked into the blades of our motors, and is bright enough that our pilot will be able to identify it and avoid it after the buoy has been deployed.



Fig. 16: The bouy and its deployment system.

Topside

Control Box

This year, we built a custom box for the control box (Fig. 17) in order to have the specific dimensions we desired, instead of using a briefcase, as in previous years. The reason for this is by building the box ourselves, we could have it perfectly fit the specific components that we planned on using. The length and width allow for the monitor to fit inside the upper half of the box and the height allows for the Intel NUC to be flush against the top panel, allowing us to press easily the power button through a hole in the top plate. The box was made of two equal-sized shells made out of veneered plywood. On the bottom sides, there are plexiglass windows that enable the us to see the electronics from all angles, which in turn allows us to better diagnose a problem if one were to arise. The top plate of the control box is covered in a sheet of clear plexiglass, which allows us to see all of the components inside. We chose to use plexiglass because it is very strong and it allows us to showcase the engineering inside of the control box. The interior of the control box is divided into three major zones (Fig 18). On the very right is all of the AC wiring. It is important that AC wiring is isolated so



Fig. 17: The control box.

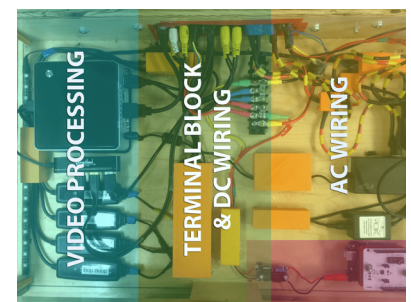


Fig. 18: The three zones in the control box.

that it does not cause interference with any of the other wires in the control box. Because safety is very important to us, we made sure that we took all necessary precautions with this wiring. All AC wiring is clearly labeled, as it is covered in yellow stripes and there is a large sign on the front of the control box which says that AC wiring has yellow stripes (Fig. 19). In addition, instead of soldering AC wires together, we used crimp connectors and screws to minimize the risk of a fire. In the center of the control box is all of the DC wiring, including the terminal block, the I/O shield, and the DC inductor power filter. The left side of the control box contains all of the control box's video processing systems, including the Intel NUC and the USB analog to digital video converters. These systems are isolated from any power wires in order to prevent interference in the signal. We tested all of the electrical systems in the control box using a multimeter, ensuring that all of the component still received enough voltage. We used an oscilloscope to see how many voltage irregularities there were. After determining that there were many voltage spikes that could potentially damage sensitive components such as cameras, we added two ferrite chokes to smooth the voltage. We also installed RGB LED strips on the two short sides of our control box. These lights are helpful because they provide more lighting in the control box so that we have more visibility and they are a clear indicator of when the control box is on. The back of the control box has two I/O shields, one on the bottom half for all of the connections to the control box (Fig. 20) and one on the top half for all the connections to the monitor (Fig. 21). We designed the I/O shields ourselves and cut them using a CNC router. The reason why we chose to use I/O shields is that they allow for all the connections going out of the control box to be easily and securely mounted, and they make the control box safer by preventing someone from sticking their hand into the control box through the back. Because our control boxes from previous years have always been very disorganized and therefore very hazardous, we decided to 3d print different cable management boxes to organize the wires inside the control box. These cable management boxes serve two purposes. They are safer, since there is less exposed wiring, and they are colored bright orange to indicate to people that they shouldn't touch them. It also significantly improves the visual appearance of the control box.



Fig. 19: The clearly labeled AC wiring in the control box.

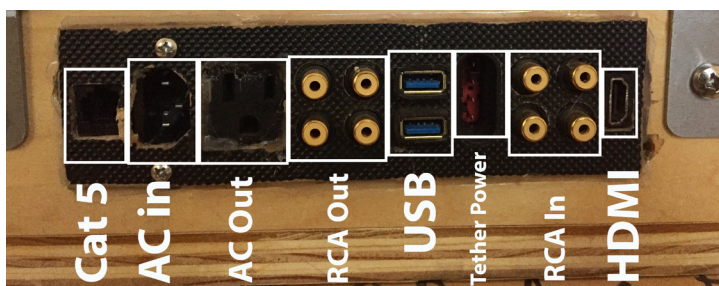


Fig. 20: The bottom I/O shield.

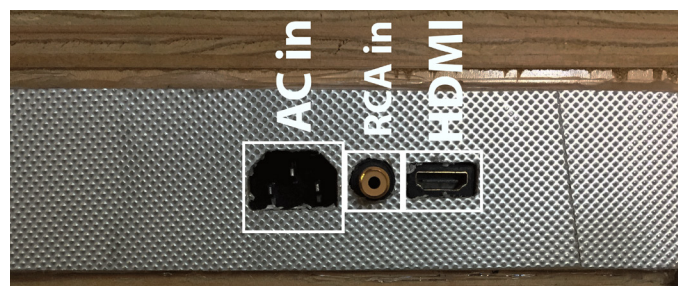


Fig. 21: The top I/O shield.

Optical Systems

Our control box utilizes two video processing systems: a primary and a backup system. Because the primary system is very complex and has many potential points of failure, we included a backup system so that if the primary system fails during the competition, we can switch to the backup system and still be able to see. The control box splits the video signals entering through the tether so that all four cameras can be used by both systems. The primary system allows for four cameras to be simultaneously displayed on screen and also allows us to quickly switch to any of the

cameras. This system works by using USB analog to digital video converters to convert the camera signals coming into the control box through the tether. The USB adapters are plugged into the four USB ports of the Intel NUC, which is running Open Broadcaster Software (OBS). Even though it is more expensive than a traditional analog setup, we chose to use a digital system for our cameras because we tried to use an analog system last year and it was inconvenient to use, and showed all the cameras but did not allow us to easily switch between them. The backup system allows for the minimum amount of functionality possible to be achieved with the greatest possible reliability. The backup system has no active video processing components, which makes it much less likely to fail. It consists of a switchboard on the back of the control box and a RCA cable that is connected to the monitor. To use this system, all the user has to do is switch the RCA cable between the different outputs of the switchboard.

— Controls —

Our robot is controlled by the Extreme 3D Pro Joystick (won in the 2016 Ranger competition), run by an Arduino Uno (Fig. 22). To facilitate the communication between the Arduino and the joystick, we integrated a SparkFun USB Host Shield as well as the LE3D arduino library. This allows the Arduino to read the Joystick's USB signal and store it as its own variable set. From there, the software sends the data to the main code. The controls for the ROV were tailored to how the pilot would drive the robot. We made the controls as simple and as straightforward as possible to ensure that the pilot would be able to drive the robot quickly without mistakes.



Fig. 22: The arduino and USB input shield.

— Code —

Since our motors are in a nonstandard configuration, we created two custom arduino scripts to run the topside and hydrotube arduinos. The topside arduino is in charge of connecting to the joystick, receiving its values, and number crunching the resulting vector fields to create the desired net thrust. To do this, our company coded the arduino to consider 4 degrees of motion: Forward-Backward, Turn Left-Turn Right, Strafe Left-Strafe Right, and Up-Down. From these values, the speed of each motor can be calculated using the vector ratios of the motors' positions to balance out each 2 dimensional vector to create the desired net 3D vector. The topside arduino then sends the resulting values for each: motor, servo, and LED to the hydrotube arduino using the RS-485 (discussed above). The bottom side arduino then receives these values and passes them off to the correct components, resulting in bot motion. To aid in mapping the cargo containers for task 4, we

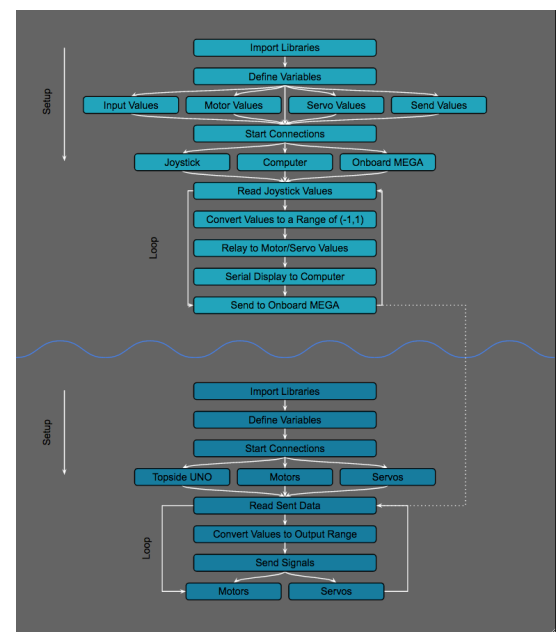


Fig. 23: Motor control software flowchart.

developed a custom program in Python to determine the direction and distance of the hazardous cargo container from the safe containers. The program uses an image of a bird's eye view of the containers (which is obtained by taking a screenshot of the screen using our Intel NUC and transferred to a laptop running the program via a flash drive). The user first identifies a reference length on the image, and supplies the computer with the measurements. This length can be the width of the cargo containers, as they have known dimensions. Next the user clicks on the centers of cargo containers, and the program uses the reference value to determine the ratio between the distance of the containers and the length of the containers, and so find the distance between them. The program also uses this to measure the exact angle between the containers, which determines the cardinal direction of the safe containers from the hazardous one. With this, the scientist can quickly map the cargo containers with machine precision.

Testing

We used a very thorough testing process to ensure that every component of the ROV is capable of being utilised to its full potential during the competition. We tested it as a whole in the pool as well as each component individually.

— Hydrotube

We tested the hydrotube with a vacuum pump to ensure watertightness (see page 10). We did this testing because we did not want the ROV to leak and break underwater.

— Motors

We created a motor testing rig that allowed us to use a spring scale to determine the thrust of the BlueRobotics T100 thrusters (see page 8). We did this to determine whether the BlueRobotics thrusters were powerful enough to justify their cost.

— Claw

We created multiple incremental iterations of the claw. We tested each iteration in the pool and developed future iterations based on what we learned from each test (see page 12). We did this in order to refine our claw in order to fully optimize it for the tasks in the competition.

— Control Box

We used a multimeter and an oscilloscope to test the current at different points in the control box (see page 14). We did this to minimize voltage drop and to make sure that there are no voltage spikes.



Fig. 24: Our completed ROV on the pool deck.

Finances

— Budget

Phoenix Electronics had an original total budget of \$2,000 from a funding grant from Bentley School. We got an additional \$100 sponsorship from Convergent Computing (CCO) and another \$100 grant from Bentley School's Student Government. Additionally, Bentley's Student Government also let us setup a bake sale fundraiser at school, which netted us \$175. Therefore, our final total budget for the regional competition was \$2,375. However, when we learned that we were advancing to the international competition, we determined that we would need additional funding. We held additional bake sales and a pizza sale at school to raise additional funds for the team. As these fundraisers have not occurred yet, we cannot determine our final budget for the international competition. In addition to needing a budget to cover the material costs to build our ROV, we also required funding to cover our team's travel expenses to both the regional and international competition. Bentley School has covered all of our travel costs for both the regional and international competitions, allowing us to focus our funds on our ROV. Our team (along with the other ROV teams from our school) took a charter bus from our school to the Monterey regional competition in Aptos, California, where we spent the night before the competition. Together this cost \$810.84. Once we advanced to the international competition, it was also necessary to get hotel reservations and pay for gas to drive the nearly 400 miles to Long Beach. We estimated our travel costs by adding the cost of the 5 hotel rooms which we need for four nights (we made reservations at the Marriott Long Beach among rooms reserved by MATE), and by multiplying 4 times the number of miles to the international competition (we are taking two vehicles, to the competition and back) by the California personal vehicle mileage reimbursement rate. Overall, our estimated travel expenses to travel to the international competition are \$4,763.98 (approximately \$4,000 for hotel rooms, and \$763.98 for transport).

— Build vs. Buy

At Phoenix Electronics we build the the majority of our mechanical and electrical systems, but in some cases we decided to buy some of our components for our major systems (specifically our propulsion and optical systems). Two main factors go into the decision to buy a major component for our ROV or control box. First, can we reasonably build an alternative of comparative quality in-house, and if so, would it cost more time and money to build such an alternative. The main components that we bought commercially were our Intel NUC for our optical systems, our BlueRobotics T100 motors, and the RCA cables in our tether. We bought our Intel Nuc to be the brains of our optical systems after we struggled to construct an effective and reliable signal interpretation system this year and in years past. The NUC arrived as just a motherboard and a case, allowing us to choose exactly what components (i.e. how much RAM, how large of an SSD, etc) we wanted to put in the NUC to achieve the level of performance we needed for minimal costs. It also saved as both time and space in the control box, as it would have taken more time and used more space to build computers for individual components. We purchased our BlueRobotics T100 motors because building motors in-house would be extremely difficult, and we would likely not be able to achieve the consistency and high level of performance given by commercially available motors.

— New vs. Reused —

For the most part, we avoid reusing parts from our old ROVs or other projects when building the new ROV. We are always trying to innovate and develop more effective and efficient systems for both the mechanical and electrical parts of our ROV, and so it is uncommon for us to have a major component that we can reuse that is compatible with our new design. Additionally, we try to keep our old ROVs intact, as they can be used to inspire others to join ROV and as tools for teaching members of other Bentley teams (such as our two Navigator teams). The parts we do use from previous ROVs are our motors, as they are lightly used and still maintain the same quality. The BlueRobotics T100 motors we use are the single largest cost for our team, so we split the motors on our last ROV with our school's other Ranger team, saving each team hundreds of dollars.

— Cost Projections —

At the beginning of the season our CFO laid out a budgeting plan with series of “sub-budgets” for each of the separate spending categories (i.e. electronics, frame, tools, etc) (Appendix C). Additionally, the CFO developed an online purchase request form, which allowed for accurate monitoring and control over the use of funds (which prevented frivolous spending and purchasing items that we already owned). Combined, these allowed us to stay under budget. We were unfortunately unable to stay within our sub-budgets for our electronics, tools, and props, but managed to stay below budget for our other budget categories, which made up for these incidents of overspending (Appendix D).

— Project Costs —

Total Projected Costs: \$2,200.00	Total Material Cost of ROV: \$2,269.35
Actual Total Costs: \$2,371.18	Travel Costs: \$5,574.82
Main Budget (for Everything Besides Travel): \$2,375.00	Total Overall Budget: \$7,949.82
Main Budget Remaining: \$3.82	Total Overall Costs: \$7,946.00

Reflections —

— Lessons Learned / Challenges —

This year we encountered and overcame multiple technical challenges, which resulted in us improving on the original ideas for our ROV. The first of these challenges came in the form of our sediment collector tool. The task of collecting and returning 100 ml of agar to the surface posed a difficult design challenge, which we attempted to solve using clever but complex solutions, such as our 3D printed motor-powered Archimedes Screw. After printing and testing multiple prototypes, we found that the screw was not sharp enough to pierce the agar without making the screw dangerously sharp. Additionally, we realized that mounting and waterproofing the motor, as well as integrating it into our control system, would be both difficult and time consuming. While the Archimedes Screw was a novel solution to a difficult challenge, it was both overly complicated and ineffective. This experience taught us that simple solutions are often more effective than more complicated ones, and that pursuing complex solutions can use valuable time and resources for a less than satisfactory result. From the sediment collector, we learned that technology can be a hindrance to find the best parts for tools and having an open mind for designs are important. When we tried to 3D print an Archimedes Screw to be powered by a motor, we realized that mounting

the motor onto the screw, waterproofing it, and then mounting the whole assembly onto the ROV would be extremely difficult. In addition, after developing it for weeks, it was not able to complete the task it was designed for. At the very beginning of the year, we designed our control box to perfectly hold our original HP2311x 23" monitor. However, the monitor was not fully functional when we first obtained it, and we were unsuccessful in our attempts to repair it. We tried to obtain a new monitor of the same model; however, we found out that it is no longer being sold. As a result, we had to use a different monitor, which does not properly fit the control box due to the difference in size. Our original camera interpretation design was based on an Intel Compute Stick. However, we had multiple issues with it. The Compute Stick only has a single USB 3.0 port, so we used a USB hub to allow us to connect all four of our video adapters. However, the single port did not have enough bus bandwidth for all four cameras, and so we were only able to use two cameras at once. The second issue with the Compute Stick was that the processor started thermal throttling down from its stock 1.4 GHz to 440 MHz, even though after extensive thermal testing we found that the temperatures were still within the operational range of the Intel Atom processor in the Compute Stick (Fig. 25). We replaced the thermal compound, the heatsink, and the fan just to be sure, but the issue persisted. There was a serious hardware issue with the Compute Stick and the single port could not supply enough bandwidth, so when we replaced it we

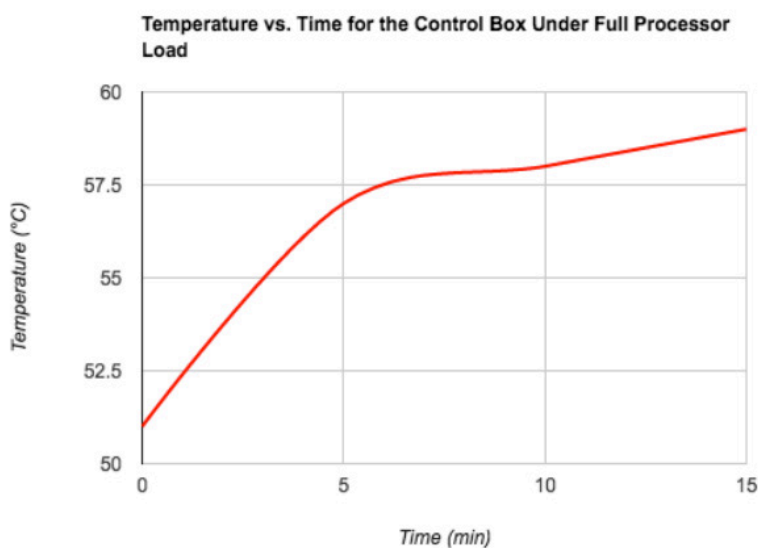


Fig. 25: A graph showing the temperature of the control box under full processor load.

chose an Intel NUC because it has four built in USB ports, and user-replaceable parts if something were to break in the future. We decided to use a VGA cable to carry the camera signals through the tether for multiple reasons (see page 11). However, there were some major issues with the VGA cable. When testing the VGA cable, we connected both ends correctly, but the camera feeds only worked intermittently and some of them did not work at all. We used a multimeter to test the conductivity of the cable's pins, and we found that some of them did not conduct across the entire cable. We opened up the VGA cable and we found that there are only 7 wires inside,

even though there are 15 contact pins on each end. What we learned from this experience is that manufacturers often cut corners in order to produce a cheaper product, and we need to read all the specifications when purchasing something.

— Future Improvements

Based on the lessons we learned this year, there are a few key things that we would like to improve upon in the future. The rest of these surrounds scheduling and project management. While we made improvements to our scheduling and project management, there is still room for improvement. Our goal was to be at least one month ahead; however, this did not happen quite as we planned. In order to complete these goals, there are some things that must be improved in order to achieve the goal. One, we need to improve the communications between subteams in order to have the process for building our ROV and control box more efficient. Two, we need to research all of the components that we plan to

purchase because we lost a lot of time trying to make the VGA cable work when a little research would have saved us a lot of time. Thirdly, we need to have a schedule set for our ROV's construction at the beginning of the year and try to meet goals of getting our ROV in the pool with plenty of time to practice and master the tasks. Lastly, we need to keep a log of dates and times of completion for parts of the ROV in order to create a simpler system for writing the technical report.

Acknowledgments

We would like to thank Matt Gardner and MATE for giving us this incredible opportunity to expand our knowledge and designing and building by hosting the ROV competition. We would also like to thank Aptos High School for hosting the Monterey Regional Competition and generously letting us use their facilities.

Thank you to Bryan Smith, Arlene Hogan, the Bentley administration, and the Bentley Board of Trustees for supporting our efforts, funding our ROV program, and improving our Makerspace and equipment.

Thank you to Jim McDonnell, our MATE mentor, for devoting so much of his time for the purpose of improving everyone's ROV experience and for always offering incredibly helpful advice.

Thank you to Julie Spector-Sprague and Joey Knapp, our faculty mentors, for supporting our team and our school's ROV program, for always offering their support, and for being there when our two hour meetings somehow turns into a four hour meetings. Without them and their support, the ROV program could not continue as it does each year.

Thank you to Rand Morimoto and Convergent Computing for sponsoring us. Without their generous financial support, we would not have been able to build the advanced optical processing system that we are using.

Thank you to the Goodman family for letting us use their pool, especially during meetings where we are still working well into the evening.

Thank you to Alex White and Underwater Missions Inc. for the computer renders of the ROV included in our technical documentation. Without his help and his Blender skills, these computer renders would not have been possible.

Thank you to Ben Tingley for helping us with electronics for so many meetings. Without his help and support, the control box would not have the optical processing systems that it does.

Finally, thank you to the dogs Jeep and Charlie for providing moral support in a way that no human is capable of doing.

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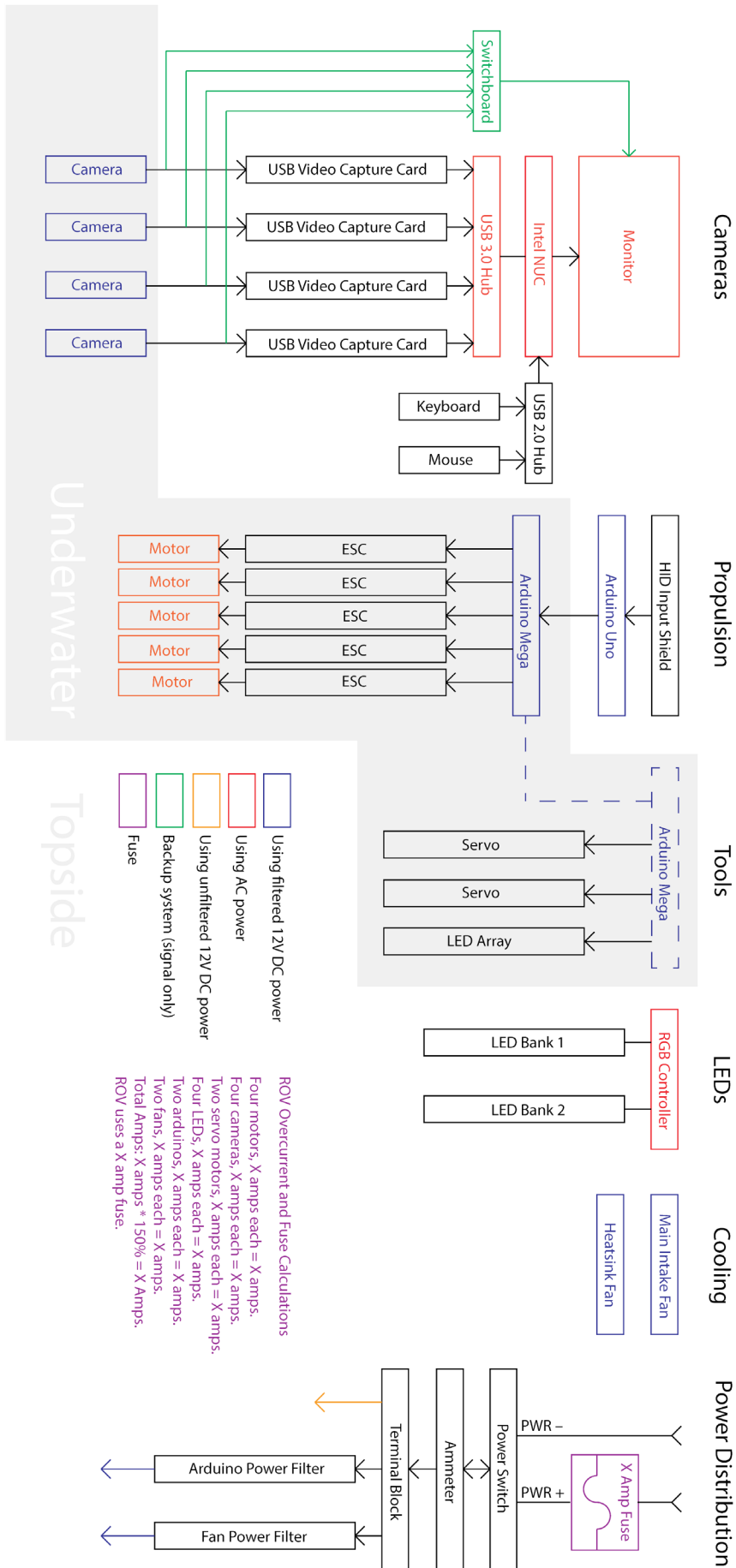
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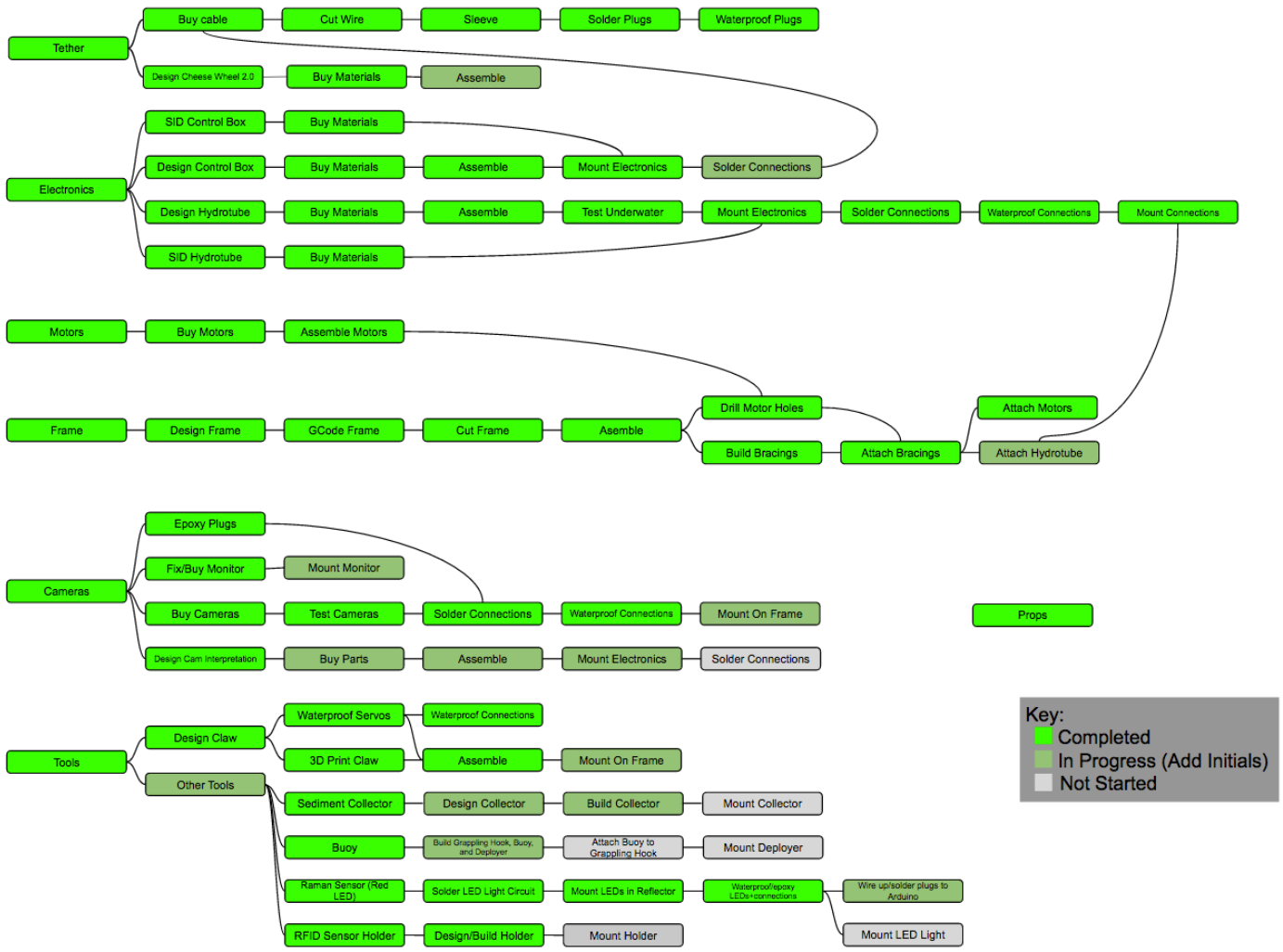
Appendix A: System Interconnection Diagram



Appendix B: Flowcharts

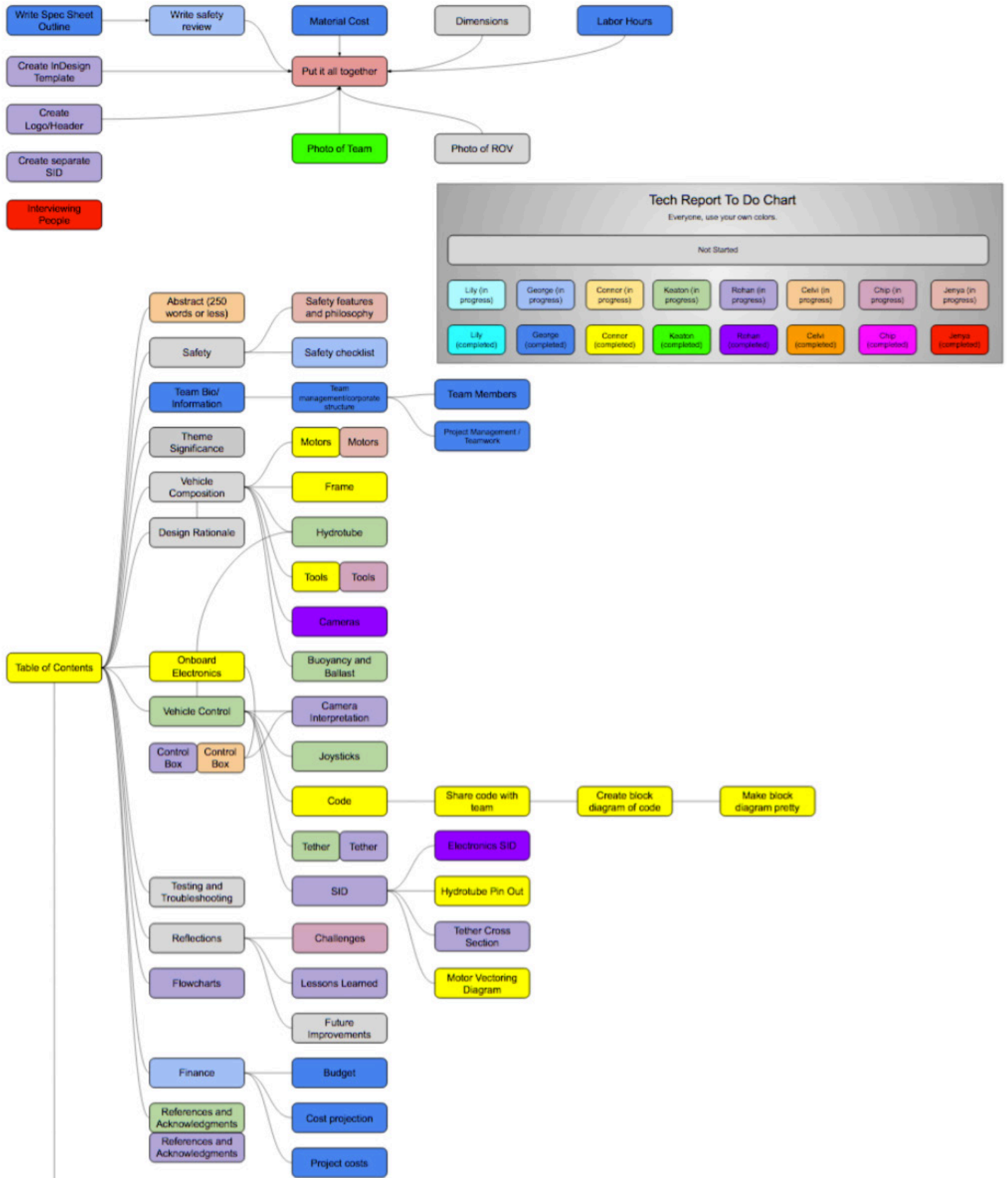
— ROV Progress

We created a flowchart using Google Drawings to track what components of the ROV were completed, what components were in progress, and what components had not been started.



Tech Report Completed Tasks

When we were writing the technical report, we created a flowchart using Google Drawings that shows who worked on what section. This allowed us to evenly distribute the workload between all members of the team. Everyone was given their own color for the diagram.



Appendix C: Finances

Budget Overview

Costs:	Cameras:	Code:	Electronics:	Frame:	Props:	Propulsion:	Tether:	Tools:	Hydrotube:	Misc:	Travel:
	\$257.08	\$0.00	\$802.18	\$34.57	\$137.31	\$667.00	\$168.66	\$72.79	\$71.67	\$159.92	\$5,574.82
Sub-Budget:	\$275.00	\$0.00	\$700.00	\$50.00	\$100.00	\$675.00	\$175.00	\$50.00	\$75.00	N/A	N/A
Sub-B Remaining:	\$17.92	\$0.00	-\$102.18	\$15.43	-\$37.31	\$8.00	\$6.34	-\$22.79	\$3.33	N/A	N/A
Total Projected Costs:		\$2,200.00									
Actual Total Costs (All Minus Travel)		\$2,371.18									
Main Budget (All Minus Travel):		\$2,375.00									
Main Budget Remaining:		\$3.82									
Total Material Cost of ROV:		\$2,269.35									
Travel Budget:		\$5,574.82									
Travel Costs:		\$5,574.82									
Total Overall Costs:		\$7,946.00									
Total Overall Budget:		\$7,949.82									
Overall Budget Remaining:		\$3.82									

Funding and Income

Funding/Income Sources:		Source:	Amount:	Income Type:
		Bentley School	\$2,000.00	School Funding
		Bentley School Student Gov't	\$100.00	Donation
		Convergent Computing (CCO)	\$100.00	Sponsor
		Bake Sale Fundraiser	\$175.00	Fundraiser
		Total Funding:	\$2,375.00	
		Total Budget:	\$2,375.00	
Travel Budget:	Nota Bene: All travel expenses were covered by Bentley School			
		Source:	Amount:	Income Type:
		Bentley School	\$5,574.82	School Funding
		Total Funding:	\$5,574.82	
		Total Budget:	\$5,574.82	

Details and Specifics

Electronics					
Date	Place of Purchase	Item	Quantity	Cost	Purpose
11/28/2016	delvie plastics	1/4" Crystal Clear Cell Cast Plexiglas	1	\$26.50	Control board of the control box
12/3/2016	Amazon	Ribbon Cable	1	\$9.59	For the monitor
12/19/2016	Amazon	32cm 3-pin Remote Control Servo ExtensionCable	1	\$8.59	ESC connections
1/13/2017	Amazon	Intel Compute Stick SBC	1	\$131.46	Brain of camera system
1/13/2017	Amazon	Fan 60mm	1	\$6.99	Need to cool box so it doesn't catch on fire.
1/13/2017	Amazon	Ribbon cable multipack	1	\$8.68	Control box connections
1/13/2017	Amazon	Standoffs (nylon)	1	\$11.99	Mounting components to inside of control box
1/13/2017	Amazon	RGB color kit, computer controlled	1	\$19.99	Aesthetics
1/13/2017	Amazon	USB breakout header	3	5.97	We need to plug things into the box.
1/13/2017	Amazon	Micro USB cable 3ft	6	4.74	Power the intel sbc, plug in internal connection
1/13/2017	Amazon	USB video dongle	4	99.92	It converts analog video to digital
1/13/2017	Amazon	AMPOMETER	1	\$18.75	Safety
1/13/2017	Amazon	60mm Fan Filter	1	\$6.95	Required for safety.
1/13/2017	Amazon	Single Pole Double Throw Switch	1	\$7.02	On and off/primary to backup switch
1/18/2017	Amazon	50 ft VGA Cable	1	\$8.55	This will carry all the signal wires for the tether

3/24/2017	Amazon	power supply for our Arduino	1	\$5.90	power supply for Arduino	Bought
3/24/2017	Amazon	Shunt Resistor	1	8.57	To ensure that our amp meter does not blow a fuse	Bought
4/11/2017	Amazon	Intel NUC NUC5CPYH	1	124.99	Replacement compute stick	Bought
4/11/2017	Amazon	4 gb 1.35 v ddr3l	1	\$25.22	Required for operation of previous item.	Bought
4/11/2017	Amazon	SATA II SSD	1	\$24.99	Required for Intel Nuc	Bought
4/17/2017	Amazon	AC Power mount plug	1	7.23	Powering our AC electronics	Bought
4/22/2017	Amazon	Anderson Powerpole Connectors	1	\$15.99	Powering the ROV	Bought
4/24/2017	Amazon	Insulated Electrical Wire Crimp Connectors	1	20.98	Powering the ROV	Bought
4/25/2017	Amazon	120V plug socket	1	7.81	Needed for AC wiring	Bought
4/25/2017	Amazon	.5 M USB extender (2 pack)	1	7.99	To plug in joystick, mouse into control box	Bought
4/30/2017	Amazon	Replacement Keyboard	1	28.99	Controlling the Intel NUC	Bought
4/30/2017	Amazon	JETech Mouse	1	8.99	Controlling the Intel NUC	Bought
4/30/2017	Amazon	Ring Magnet	1	11.99	Voltage smoothing	Bought
			Total:	\$802.18		

Cameras

Date	Place of Purchase	Item	Quantity	Cost	Purpose	Bought/Previously owned/Donated
12/6/2016	Amazon	Esky EC170-11 Waterproof Camera	6	\$120	Cameras for the ROV	Bought
1/13/2017	Amazon	HDMI extension dongle	1	\$6.59	So the monitor can connect to the video processing.	Bought
1/13/2017	Amazon	hp 2311x monitor	1	\$94.68	Monitor for the control box	Bought
4/3/2017	Amazon	RCA splitter cable M to 2xF	2	\$13.88	Splits signal between primary and secondary systems	Bought
4/25/2017	Amazon	1.5ft HDMI extender cable	1	5.99	To connect monitor to Intel NUC	Bought
5/2/2017	Amazon	RCA Couplers	1	5.99	Camera signal carrier	Bought
5/4/2017	Amazon	RCA CABLE 1.5ft	1	9.95	Carrying camera signals	Bought
			Total:	\$257.08		

Date	Place of Purchase	Item	Quantity	Cost	Purpose	Bought/Previously owned/Donated
Multiple Dates	TAP Plastics	High Density Plastic	N/A	\$34.57	The frame is built out of HDP	Bought
N/A	Home Depot	Assorted Machine Screws	N/A	\$6.97	Used to assemble the frame	Previously owned
N/A	Home Depot	3/4 in. x 48 in. Aluminum Flat Bar with 1/8 in. Thick	2	\$5.98	Used to assemble the frame	Previously owned
N/A	Home Depot	Assorted Rivets	N/A	\$7.97	Used to assemble the frame	Previously owned
N/A	Home Depot	Assorted Washers	N/A	\$6.97	Used to assemble the frame	Previously owned
N/A	Home Depot	1 in. x 96 in. Aluminum Angle Bar	1	\$13.94	Used to assemble the frame	Previously owned
			Total (New Parts):	\$34.57		

Props

Nota Bene: Prop costs were split among all four Bentley Upper School ROV teams. Costs listed are Phoenix Electronics' share of the costs.

Date	Place of Purchase	Item	Quantity	Cost	Purpose	Bought/Previously owned/Donated
N/A	Home Depot	Misc Props Supplies:	N/A	\$79.67	Props	Bought
N/A	Home Depot	Misc Props Supplies:	N/A	\$44.12	Props	Bought
1/13/2017	Amazon	CatSe Ethernet Cable 2 PACK	1	\$1.70	Props	Bought
1/13/2017	Amazon	Chanzone 100pcs 5mm LED Lamp Kit	1	\$4.50	Props	Bought
1/13/2017	Amazon	10-Piece Galvanized Steel Tent Pegs	1	\$1.55	Props	Bought
5/7/2017	Amazon	Food grade agar	1	\$5.77	Props	Bought
			Total:	\$137.31		

Propulsion

Date	Place of Purchase	Item	Quantity	Cost	Purpose	Bought/Previously owned/Donated
11/27/2016	BlueRobotics	T100 Thruster w/	4	\$476.00	Motors make the ROV go	Bought
11/27/2016	BlueRobotics	Basic ESC	4	\$100.00	These control the motors	Bought
N/A	BlueRobotics	T100 Thruster w/	1	\$119.00	Motors make the ROV go	Previously Owned
11/27/2016	BlueRobotics	2 Blue Robotics ESCs	2	\$50.00	These control the motors	Bought
1/9/2017	BlueRobotics	Mounting brackets for T100 thrusters	5	\$25	Motor mounting	Bought
3/1/2017	BlueRobotics	Enclosure Vent and Plug	1	\$8	Sealing	Bought
3/29/2017	BlueRobotics	Enclosure Vent and Plug	1	\$8	Sealing	Bought
			Total (New Parts):	\$667.00		
			Total (New plus previously owned):	\$786.00		

Tools

Date	Place of Purchase	Item	Quantity	Cost	Purpose	Bought/Previously owned/Donated
1/14/2017	Sparkfun	Servo - Hitec HS-422	3	\$39.80	Claw servos	Bought
3/8/2017	Amazon	Flowermoon DC Motor	1	\$4.99	Agar screw motor	Bought
4/5/2017	Target	Supersoaker	1	\$20.00	Suction system for 3rd gen. agar collector	Bought
4/5/2017	Ace Hardware	Hydraulic tubing	1	\$5.00	Part of 3rd gen. agar collector	Bought
4/7/2017	Ace Hardware	Waterproof casing	1	\$3.00	4th gen. agar collector	Bought
			Total:	\$72.79		

Hydrorube

Date	Place of Purchase	Item	Quantity	Cost	Purpose	Bought/Previously owned/Do
15/2017	Amazon	Syrene Butadiene Rubber	1	\$9.19	For the hydrorube gasket	Bought
31/2017	Amazon	RGB LED kit	1	\$20.99	Aesthetics and lighting for ROV	Bought

Misc

Date	Place of Purchase	Item	Quantity	Cost	Purpose	Bought/Previously owned/Do
12/2017	Amazon	Hawaiian Shirts	8	\$159.92	Team uniforms	Bought
			Misc. Total:	\$159.92		

Nota Bene: Travel costs for the regional competition were split among all four Bentley Upper School ROV teams. Costs listed are Phoenix Electronics' share of the costs.

Driving costs for international competition were calculated using the California personal vehical mileage reimbursement rate

Travel Expenses:	Date	Place of Purchase	Item	Quantity	Cost	Purpose	Bought/Previously owned/Donated
Regional Competition	N/A	N/A	Charter Bus	N/A	\$508.44	Travel Expenses	Bought
Travel Expenses	N/A	N/A	Hotel Rooms	N/A	\$302.40	Travel Expenses	Bought
International Competition	N/A	N/A	Van and car	N/A	\$763.98	Travel Expenses	Bought
Travel Expenses	N/A	Marriot Long Beach	Hotel Rooms	N/A	\$4,000.00	Travel Expenses	Bought
			Travel Total:	\$5,574.82			

12/6/2016	Amazon	Esky EC170-11 Waterproof Camera	6	\$120	Cameras for the ROV	Bought
1/13/2017	Amazon	HDMI extension dongle	1	\$6.59	So the monitor can connect to the video processing.	Bought
1/13/2017	Amazon	hp 2311x monitor	1	\$94.68	Monitor for the control box	Bought
4/3/2017	Amazon	RCA splitter cable M to 2xF	2	\$13.88	Splits signal between primary and secondary systems	Bought
4/25/2017	Amazon	1.5ft HDMI extender cable	1	5.99	To connect monitor to Intel NUC	Bought
5/2/2017	Amazon	RCA Couplers	1	5.99	Camera signal carrier	Bought

Date	Place of Purchase	Item	Quantity	Cost	Purpose
11/5/2016	Amazon	Waterproof Electrical Connector Plug Kit	2	\$27.98	Waterproof electrical connections
11/5/2016	Amazon	Waterproof Electrical Connector Plug Kit	2	20.78	Waterproof electrical connections
11/5/2016	Amazon	Waterproof Electrical Connector Plug Kit	2	20.38	Waterproof electrical connections
1/21/2017	Amazon	3/4 sheath for tether	1	\$27.50	Tether sheathing
2/19/2017	Amazon	3/4 inch diameter tether sheathing	1	\$27.50	Tether sheathing
2/27/2017	Amazon	15Pin Jack Port to Terminal Breakout Board Connector	2	\$15.58	Tether connections
3/1/2017	Amazon	100 ft 10 gauge avg Speaker Wire	1	\$23.95	Tether connections
5/2/2017	Amazon	USB extender cable	1	4.99	Carrying camera signals
			Total:	\$168.66	

Tether